Journal of Crop Improvement
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t792303981

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Online publication date: 06 November 2010

To cite this Article Meng, Jie , Xu, Yanli , Li, Shuxian , Li, Chunjie , Zhang, Xingyi , Dong, Dekun and Chen, Pengyin(2010) 'Soybean Growth and Soil Microbial Populations under Conventional and Conservational Tillage Systems', Journal of Crop Improvement, 24: 4, 337 — 348

To link to this Article: DOI: 10.1080/15427528.2010.499864

URL: http://dx.doi.org/10.1080/15427528.2010.499864

Journal of Crop Improvement, 24:337–348, 2010

ISSN: 1542-7528 print/1542-7535 online
DOI: 10.1080/15427528.2010.499864

Soybean Growth and Soil Microbial Populations under Conventional and Conservational Tillage Systems

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*Tillage systems play an important role in crop growth and soil improvement. This study was conducted to determine the best tillage system for the dark-soil area of northeast China with dark-clay soil type (Millisol) and to examine the influence of different tillage systems on soybean [*Glycine max *(L.) Merr.] growth and soil microbial populations. Three conventional tillage systems and two conservational tillage systems were tested. Plant height and biomass as reflected by dry shoot and dry root weight*

We would like to give our special thanks to the staff of Hailun Agro-Ecological Experiment Station of Chinese Academy for field plot managements and to Mr. Quan Zhao for helping us sample the plants materials and soils.

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under the no-till system were significantly reduced as compared with other tillage systems. The bacterial, fungal, and actinomycete populations reached their highest levels at soybean R2 (blooming) stage. The disease severity of root rot and population dynamics of bacteria, fungi, and actinomycetes in conservational tillage appeared to be higher than those in conventional systems; the latter were associated with an increased populations of Fusarium *spp. and* Trichoderma *spp. Based on these research findings, a conventional tillage with reduced plowing frequency and intensity and increased crop-residue coverage would be a reasonable recommendation for soybean production in the dark-soil area of northeast China.*

KEYWORDS Tillage, soybean, plant growth, microbial population, soil health, plant disease

INTRODUCTION

Tillage is an important management practice in agricultural production. It includes conventional tillage systems, such as rotary, combined, or moldboard plow and conservational tillage systems, such as reduced tillage or no-till. Tillage systems can alter soil ecological factors that include, but are not limited to, moisture, temperature, pH level, and fertility (Li & Hu, 2008). These factors can significantly affect crop growth in various tillage systems and also have important impact on the composition, quantity, and distribution of soil microbes. No-till systems can keep the microbial populations in the topsoil at a high and stable level (Gao, Zhu, & Chen 1994; Lupwayi et al. 2001; Kosmas et al. 2001; Qiang et al. 2004). There is also evidence that proper tillage or subsoiling can significantly increase the population of active microbes (Gao et al. 2001; Wang et al. 2006).

The dark-soil area in northeast China is an important grain-production base. Soil degradation is very common in this area because of long-term excessive reclamation and erosion. Conservational tillage has proved effective to improve physical and chemical properties of the soil, reduce organic-matter loss, and prevent erosion by reducing tillage intensity and increasing surface area covered by crop residues. Selection of proper tillage systems for a certain ecotype or production area will be an important issue for the sustainable utilization of soil. To determine which tillage system is favorable for the dark-soil area of northeast China, the growth of soybean and the populations of soil microbes were evaluated under five different tillage systems in this study.

MATERIALS AND METHODS

Field Experiments

Experiments were conducted in the Hailun Agro-Ecological Experiment Station of the Chinese Academy of Sciences in 2008. The soil in this area is dark clay (Millisol). A corn (*Zea mays*)-soybean (*Glycine max*) rotation system had been used on the test site since 2003. The local soybean cultivar 'Heinong 48' was planted in 2008 in the test fields with a plot size of 40.0 × 8.4 m. Five tillage treatments were used, which included three conventional tillage systems (rotary, combined and moldboard plow) and two conservational tillage systems (reduced tillage and no-till). These treatments are described below:

1. Rotary plow—rotary plowed after harvest in fall;
2. Combined plow—furrow subsoiling in summer, and moldboard plowed in fall;
3. Moldboard plow—moldboard plowed in fall;
4. Reduced tillage—furrow subsoiling in summer, and leave stubble in the field after harvest; and
5. No-till: chop crop stubbles and spread them in the field after harvest, no plowing or other tillage.

Tillage treatments were arranged in a randomized complete block design with three replications where each treatment appeared once and was randomly assigned in each block (replication). Field managements were identical among treatments except for the different tillage systems used.

Plant and Microbial Measurements

Soybean growth and development were determined at seedling stage. Ten plants were randomly sampled in each plot. Plant height was measured from soil line to shoot tip. Shoot and root were separated from the soil line; their dry weights were determined by drying the samples at 105°C for 30 min and then at 85°C until a constant weight was obtained.

Disease severity for soybean root rot was determined at seedling stage using a 0 to 5 scale where 0 = healthy root without lesions; 1 = a few occasional and isolated lesions on the primary roots, but no lesions on the secondary roots; 2 = lesions connected and covered less than $\frac{1}{4}$ of the primary roots; surface area, occasional lesions on the secondary roots; 3 = lesions covered $\frac{1}{4}$ -$\frac{1}{2}$ of the primary roots' surface area and a large number of, but separate, lesions on the secondary roots; 4 = lesions covered $\frac{1}{2}$ - $\frac{3}{4}$ surface area of the primary roots and a large number of connected lesions on the secondary roots with partial fall-off; 5 = all the primary roots were covered by lesions with severe root rot and nearly all the secondary roots fell off.

The population dynamics of culturable bacteria, fungi, and actinomycetes in the non-rhizosphere soil were monitored during the entire developmental stages of soybean, i.e., from emergence (VE) to maturity (R8). Soil samples were taken and mixed from five random spots in each plot using an augar. Briefly, the topsoil (0–5 cm depth) was discarded to avoid possible influence of air on the soil surface. Soil samples from a 5 to 20 cm depth were mixed thoroughly, sealed in sterile bags, and stored in an icebox. The fresh soil samples were sifted through a 2 mm sieve prior to evaluating microorganisms. Beef extract peptone medium, Rose Bengal medium, and Gause's No.1 medium were used for the culture of bacteria, fungi, and actinomycete, respectively, according to the methods described by Xu & Zheng (1986). Selective media, Bangladesh Red PCNB medium (Sun, Duan, & Lu 2006) and Malachite green agar (Castellá et al. 1997), were used to grow cultures of the pathogenic fungi *Trichoderma* spp. and *Fusarium* spp., respectively. They were then identified according to the method described by Gams & Bissett (1998) and Wei (1979).

The biostatistical software Data Processing System (DPS v3.01, Hangzou Ruifeng Information Technology Co., China) was used for statistical analyses. Data were analyzed using one-way ANOVA and treatment effects were compared via the least significant difference (LSD) at $P \leq 0.05$.

RESULTS

Effects of Different Tillage Systems on Soybean Growth and Root Rot Disease

Plant height, shoot, and root dry weights were analyzed under different tillage systems at the seedling stage. No significant ($P > 0.05$) difference in plant height was observed among reduced tillage, rotary plow, combined plow, and moldboard plow systems. However, plant height in the no-till system was significantly ($P < 0.01$) reduced as compared with any of these tillage systems. Rotary and combined tillage systems produced taller plants than reduced tillage and moldboard plow system did (Figure 1). Plant biomass showed a similar trend as plant height. Plant dry shoot and dry root weights were not significantly ($P > 0.05$) different, although numerically there were differences among reduced tillage, rotary plow, combined plow, and moldboard plow systems. But the dry shoot and root weights were significantly lower in the no-till system as compared with other tillage systems. In addition, rotary and moldboard systems appeared to produce more shoot biomass than the reduced and combined tillage systems (Figure 2). There was no significant ($P > 0.05$) difference in disease index among all the tillage treatments, although the no-till system tended to give somewhat

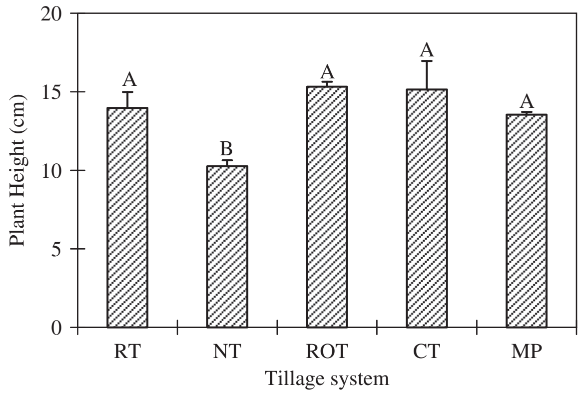

FIGURE 1 Soybean plant heights under different tillage systems. RT: reduced tillage; NT: no tillage; ROT: rotary tillage; CT: combined tillage; MP: moldboard plow. Histogram bars with the same letter are not significantly ($P > 0.05$) different.

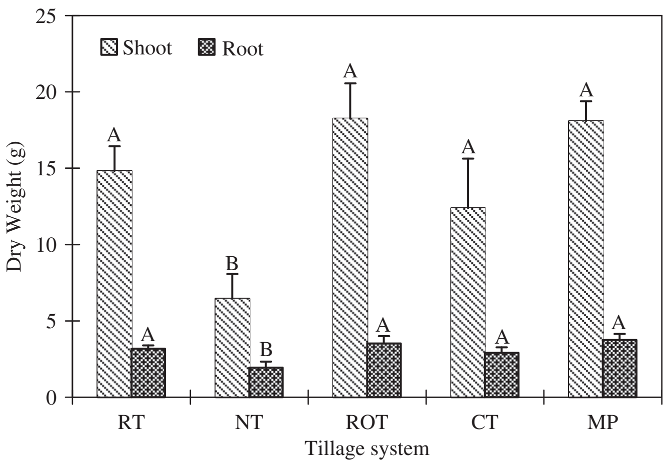

FIGURE 2 Soybean dry weights of shoot and root under different tillage systems. RT: reduced tillage; NT: no tillage; ROT: rotary tillage; CT: combined tillage; MP: moldboard plow. Histogram bars with the same letter are not significantly ($P > 0.05$) different.

higher disease severity, whereas disease severity under the rotary tillage system was relatively low (Figure 3).

Effects of Different Tillage Systems on Soil Microorganisms

The population dynamics of soil bacteria, fungi, and actinomycetes were assessed at five different stages: before sowing, at seedling, at bloom, at pod filling, and at maturity. The populations of these soil microorganisms

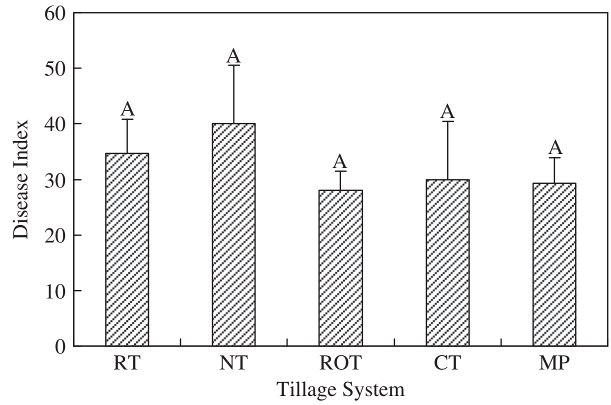

FIGURE 3 Soybean root rot disease index under different tillage systems. RT: reduced tillage; NT: no tillage; ROT: rotary tillage; CT: combined tillage; MP: moldboard plow. Histogram bars with the same letter are not significantly ($P > 0.05$) different.

in different tillage systems showed a similar trend across time during these five stages. The microbial populations stayed at low levels at the beginning of the season (before sowing and seedling stage) and increased gradually as the growing season progressed, achieving the highest level at bloom and then decreasing gradually to the lowest level at maturity (Figures 4, 5, 6). When comparing different tillage treatments at a specific growth stages, no significant difference in microbial populations was found among all tillage treatments. However, conservational tillage systems (no-till and reduced tillage) appeared to contribute to lower microorganism populations than

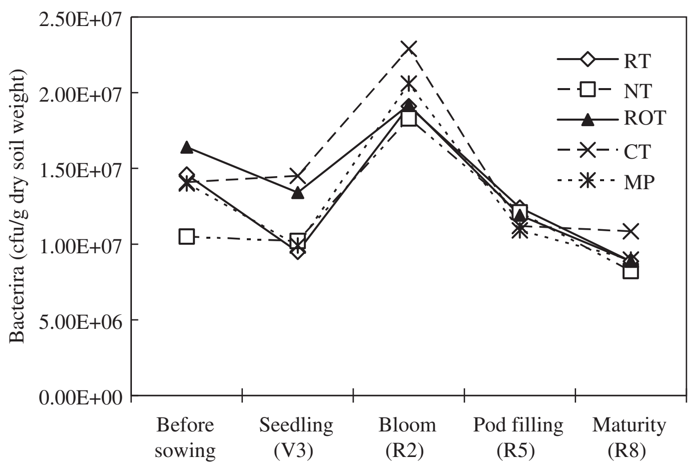

FIGURE 4 Change of soil bacteria dynamics under different tillage systems. RT: reduced tillage; NT: no tillage; ROT: rotary tillage; CT: combined tillage; MP: moldboard plow.

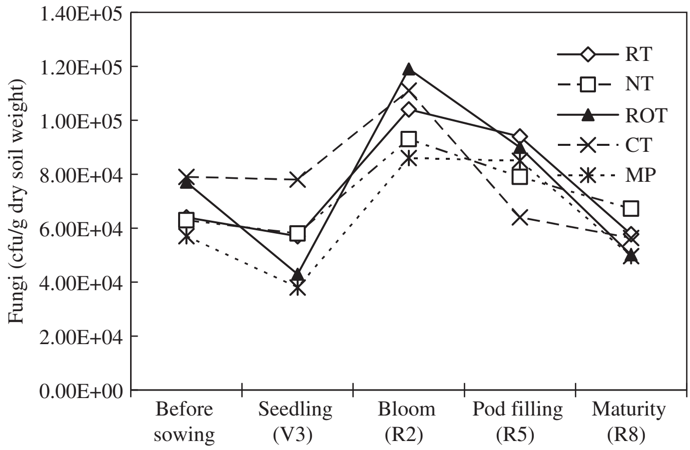

FIGURE 5 Change of soil fungal dynamics under different tillage systems. RT: reduced tillage; NT: no tillage; ROT: rotary tillage; CT: combined tillage; MP: moldboard plow.

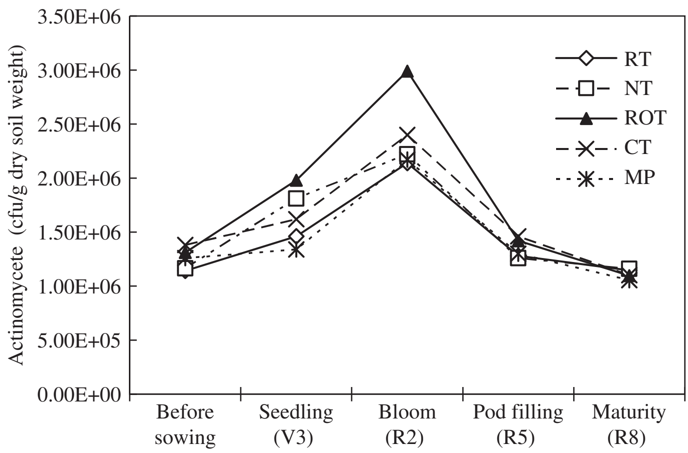

FIGURE 6 Dynamics of actinomycete activities in soils under different tillage systems. RT: reduced tillage; NT: no tillage; ROT: rotary tillage; CT: combined tillage; MP: moldboard plow.

conventional tillage systems (rotary plow, combined plow, and moldboard plow) in most situations. Rotary or combined tillage tended to enhance the microbial populations at most of the growth stages.

Effects of Different Tillage Systems on the Predominant Fungal Species in Soil

The predominant fungal species *Trichoderma* spp. and *Fusarium* spp. were monitored in different tillage systems throughout the growing season.

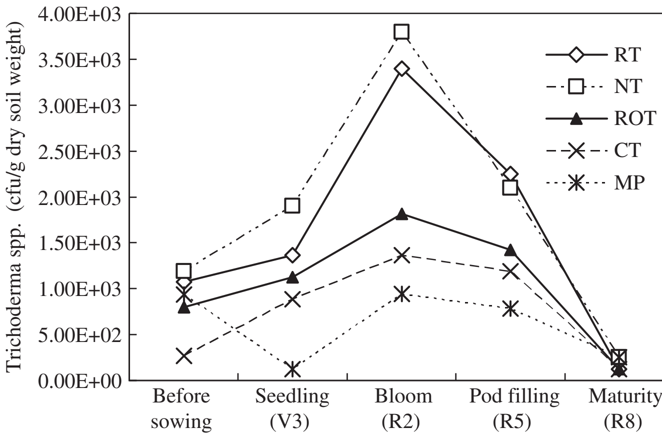

FIGURE 7 Change of *Trichoderma* dynamics in soils under different tillage systems. RT: reduced tillage; NT: no tillage; ROT: rotary tillage; CT: combined tillage; MP: moldboard plow.

The population dynamic of *Trichoderma* spp. showed a similar pattern as those of other microbial populations: starting from a low level at the beginning of the growing season (V3), increasing to the highest level at bloom (R2), and then declining gradually to a low level at maturity (R8) (Figure 7). No-till or reduced tillage appeared to contribute to higher, although not significant ($P > 0.05$) at most stages, population dynamics of *Trichoderma* spp. than other tillage systems. The difference was larger at bloom than at other growth stages. The population dynamics of *Fusarium* spp. also showed a low-high-low trend feature, except that the highest level was reached at the pod filling stage (Figure 8). Although there was no significant difference ($P > 0.05$) in the population dynamics of *Fusarium* spp. among all tillage systems, conservational tillage systems (no-till and reduced tillage) appeared to give higher populations of *Fusarium* spp. at most of the growth stages. This effect was most evident at the pod-filling stage (Figure 8).

DISCUSSION

Tillage systems have important impact on soybean growth. As demonstrated in this study, conservational tillage systems greatly reduced plant height, shoot weight, and root weight. This could be attributed to the physical, chemical, and biological properties of the soil associated with different tillage systems. It has been shown that multiple factors, such as water, oxygen, temperature, and soil properties (physical, chemical, and biological) play an important role in the differences in soybean growth (Malicki et al. 1997). Soils in the no-till system tend to have high mechanical resistance

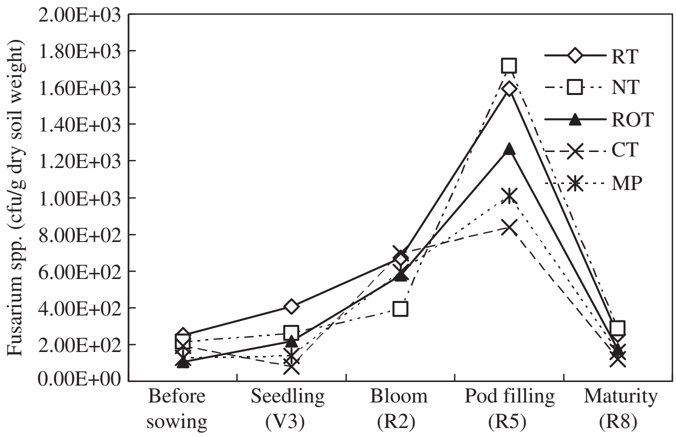

FIGURE 8 Change of *Fusarium* dynamic in soils under different tillage systems. RT: reduced tillage; NT: no tillage; ROT: rotary tillage; CT: combined tillage; MP: moldboard plow.

and low ventilation ability. The growth of root systems and the uptake abilities for water and nutrients might be restricted when crops are grown on this type of soil (Hughes et al. 1992; Kirkegaard et al. 1995; Ma, Tang, & Ji 2004). Furthermore, soil temperature of no-till system is lower than that of other tillage systems, and it would be adverse for seed germination and/or seedling growth (Zhang et al. 2009). All these adverse effects appear to lead to reduced plant height and biomass when soybeans are grown under the no-till system. Because conventional tillage systems such as moldboard plow or rotary plow can loosen the soil and help plant root system grow and expand, they have favorable effects on soybean growth and accumulation of root and shoot dry matter. However, there is also a conflicting report that the no-till system can increase the available water in the rhizosphere and will be advantageous for plant growth**.** This discrepancy may be because of the diverse ecotypes used in each study. Further research will be needed to resolve this issue.

As an important attribute of soil fertility and standard to evaluate on-farm management practices, the types and quantities of microbial population can have an impact on crop growth. The population of all microorganisms monitored in this study showed low-high-low trends throughout the growing season. This pattern appears to be associated with the soil temperature throughout the growing season. Dynamics of soil temperature seem to account for the changes of these microorganism populations—the relatively low soil temperature at the beginning of the growing season might have restricted the growth of microorganisms; optimum temperature and soybean root exudates at blooming stage likely led to their highest levels; and the subsequent decrease of soil temperature at maturity resulted in declining of microorganism populations. The higher metabolic activity, photosynthesis, and transpiration efficiency; root exchange capacity for water and nutrition; and enhanced energy exchange between plant and soil at blooming stage (Chen & Li 1979) could be another reason for the highest levels of microorganism populations. On the other hand, changes in soil nutrition, moisture, and root exudates at later growth stages of soybean (Ma, Tang, & Ji 2004) could contribute to the decrease of microorganism.

In our study, conservational tillage systems (no-till and reduced tillage) reduced the population of culturable bacteria, fungi, and actinomycetes to certain extents as compared with conventional tillage systems. This negative impact of conservation tillage on microbial populations could also be attributed to soil properties. The minimum soil disturbance in conservational tillage systems has been shown to have negative impacts on soil porosity, thereby slowing down the mineralization rate and subsequently reducing the soil fungi activities (He et al. 2007). Soil temperature and moisture might be additional reasons for the decrease in these microorganisms in conservational tillage systems. On the other hand, there is also a report that continuous coverage with crop residues can increase the fungal populations in the no-till system (Gao et al. 2001). This disparity might be a result of the complex interactions among different environmental factors in diverse ecotypes.

Fusarium spp. is a widespread pathogenic fungus in the soil that can cause leaf wilt or root rot in many plant species by infecting their vascular system (Steinkellner & Langer 2004). *Trichoderma* spp. is a very common fungus; it is an advantageous fungus in the soil because of its antagonism effect on other pathogens (Lu 1993). The populations of *Fusarium* spp. and *Trichoderma* spp. in conservational tillage systems appear to be higher than those in conventional tillage systems despite the fact there were no statistical differences. These observations are consistent with the results reported previously (Steinkellner & Langer 2004) and are also supported by the disease indices of soybean root rot in this study. The coverage with plant debris under the conservational tillage system has been proved to keep the soil moisture and humus content at a relatively high level (Zhou 1997; Gao et al. 2004), which likely created a good growing condition for both the pathogenic fungus *Fusarium* spp. and the favorable fungus *Trichoderma* spp.

Continuous cropping can cause deterioration of the rhizosphere environment, aggravation caused by pests and diseases, limited development of soybean root, and eventually loss of yield. Rotary and moldboard plow have been proved to be a success in reducing problems associated with continuous cropping of soybeans (Xu, Han, & Li 1999; Li et al. 2008). Our results also indicated that conventional tillage systems can improve the crop-growing environments, increase populations of microorganisms, decrease populations of some pathogenic fungi, and reduce incidence and severity of root rot of soybeans. However, more inputs and costs will be required when conventional tillage systems are used. Moreover, serious soil erosion will be another important disadvantage associated with conventional tillage systems. Therefore, reducing plowing frequencies and intensities and increasing crop residue coverage on soil are recommended for crop management, which should provide benefits for both ecotypic well-being and economical efficiency.

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